



MRF[®] developments & asphere metrology using VON[™] Technology

presented to:

Mirror Technology SBIR/STTR Workshop

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Acknowledgements:

NASA: Scott Antonille, Dave Content, John Hraba, Phil Stahl, John West ...

+ many DoD sponsors

- Asphere Stitching Interferometry (ASI™)
 - Variable Optical Null (VON™) Technology
- Large optic polishing with MRF®
- New aspheric representation

- Asphere metrology typically requires dedicated – and costly – null lenses, which can often be the pacing element in optics manufacturing
- We are reporting here on a – NASA and DoD – SBIR success story in developing a metrology tool capable of:
 - Measuring concave or convex surfaces
 - Measuring flat, spheres and aspheres
 - ... *without* dedicated null lenses or tooling
 - For both surface measurements and, in some cases, transmitted wavefronts (e.g. flat & dome TWF)

Asphere Stitching Interferometer (ASI™)

- Measure flats, spheres, and on-axis aspheres
 - Diameters up to 200 mm in all cases, up to 300 mm in most cases
 - Slopes up to 90 degrees, i.e. full hemispheres concave or convex
- Aspheric departures up to 1,000 waves (~630+ microns) from best-fit-sphere or more
 - Depends on profile and radius
- Automated part alignment and positioning
- ~1 meter of Z-axis travel for automated radius measurements (using cats-eye + stitching)
- High spatial resolution output maps
 - E.g. (500 x 500) pixels, (1K x 1K), (2K x 2K)...
 - = Excellent lateral Frequencies capabilities
 - Important for metrology of Mid Spatial Frequencies, tight Edge Exclusion, quilting errors etc

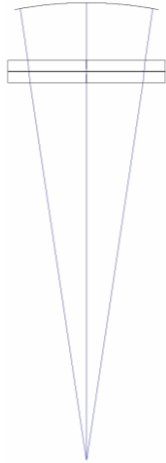


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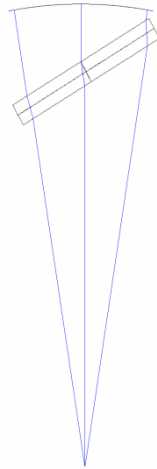
Maximum wedge

-

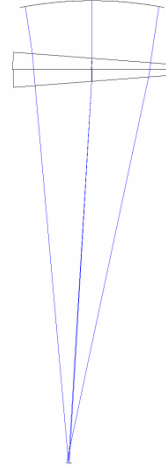
VON Configurations



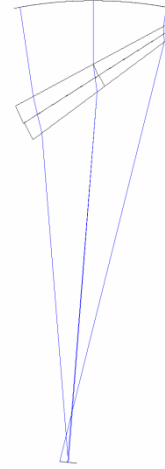
No Tilt
No Wedge



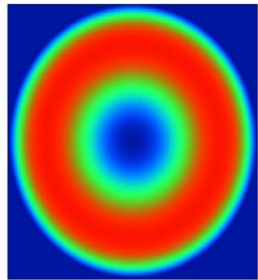
Tilt only



Wedge only



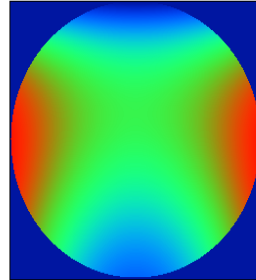
Tilt and
Wedge



WAVEFRONT FUNCTION

FRT JTN 9 2009
0.5500 μm RT 0.0000, 0.0000 DEG
PERR TO VALLEY = 0.2319 WAVES, RMS = 0.0688 WAVES.
SURFACE THICK
EXIT PUPIL DIAMETER: 3.2364E+009 MILLIMETERS

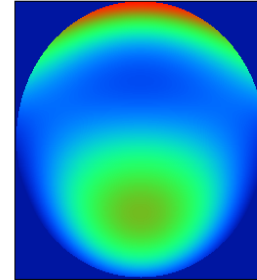
F3-3_RISLEY_SENSITIVITY.Z
CONFIGURATION 1 OF 1



WAVEFRONT FUNCTION

FRT JTN 9 2009
0.5500 μm RT 0.0000, 0.0000 DEG
PERR TO VALLEY = 46.6128 WAVES, RMS = 0.7316 WAVES.
SURFACE THICK
EXIT PUPIL DIAMETER: 3.2364E+009 MILLIMETERS
TILT REMOVED: X = 0.0000, Y = -0.6374 WAVES

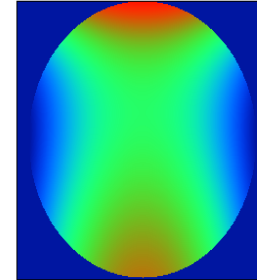
F3-3_RISLEY_SENSITIVITY.Z
CONFIGURATION 1 OF 1



WAVEFRONT FUNCTION

FRT JTN 9 2009
0.5500 μm RT 0.0000, 0.0000 DEG
PERR TO VALLEY = 93.1167 WAVES, RMS = 16.6249 WAVES.
SURFACE THICK
EXIT PUPIL DIAMETER: 3.2478E+009 MILLIMETERS
TILT REMOVED: X = 0.0000, Y = 76.5844 WAVES

F3-3_RISLEY_SENSITIVITY.Z
CONFIGURATION 1 OF 1



WAVEFRONT FUNCTION

FRT JTN 9 2009
0.5500 μm RT 0.0000, 0.0000 DEG
PERR TO VALLEY = 1263.6748 WAVES, RMS = 238.6706 WAVES.
SURFACE THICK
EXIT PUPIL DIAMETER: 3.5374E+009 MILLIMETERS
TILT REMOVED: X = 0.0000, Y = 170.8002 WAVES

F3-3_RISLEY_SENSITIVITY.Z
CONFIGURATION 1 OF 1

small
spherical

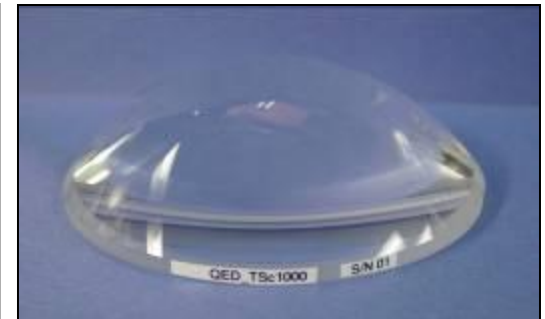
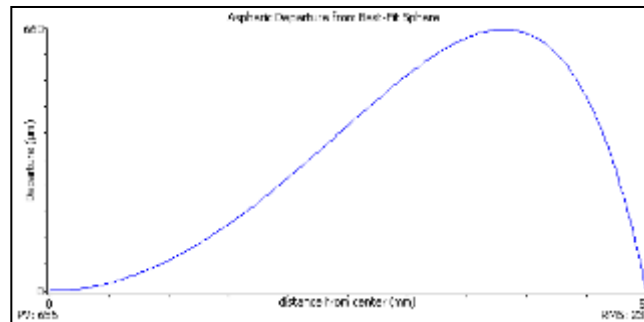
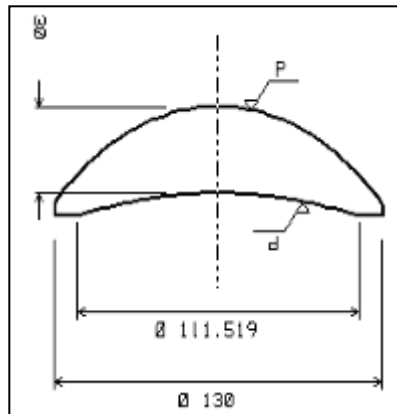
mostly
astigmatism

mostly
coma

coma and
astigmatism

Example: 1,000 Waves Asphere

- 118 mm CA
- 72 mm vertex radius
- 656 micron departure from best fit sphere
- High NA and aspheric departure make this asphere difficult to measure with other techniques



Variable Optical Null (VON) Device

See video...

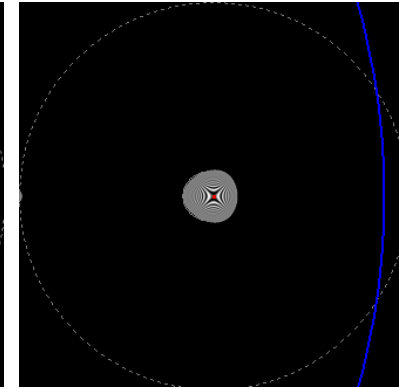
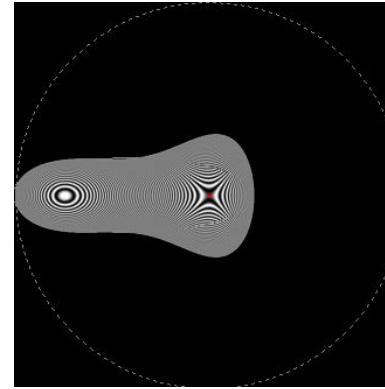
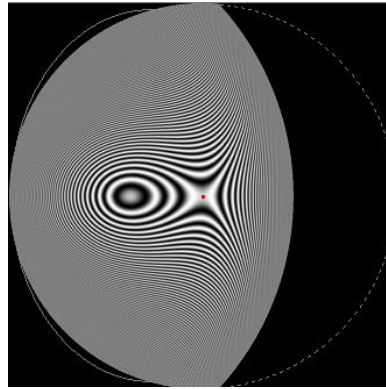
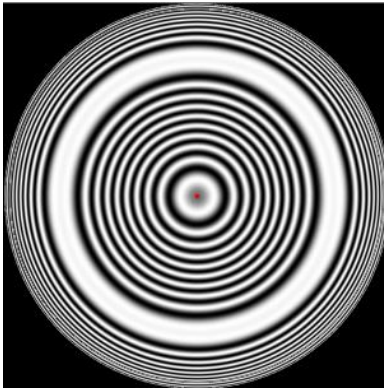
$R = 0$ mm

$R = 16$ mm

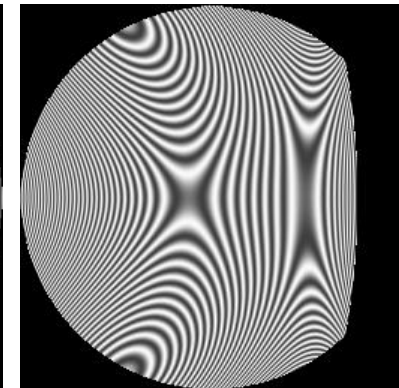
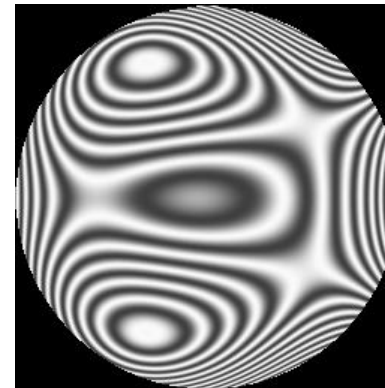
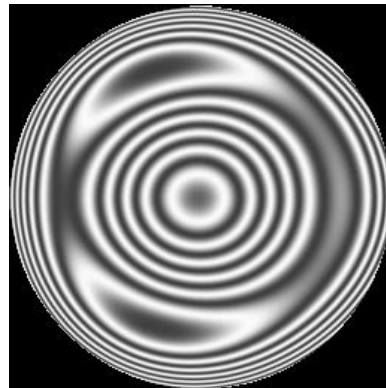
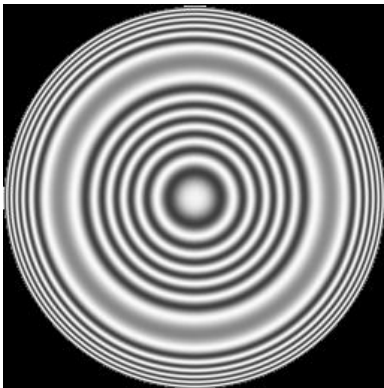
$R = 31$ mm

$R = 46$ mm

**Without
VON**

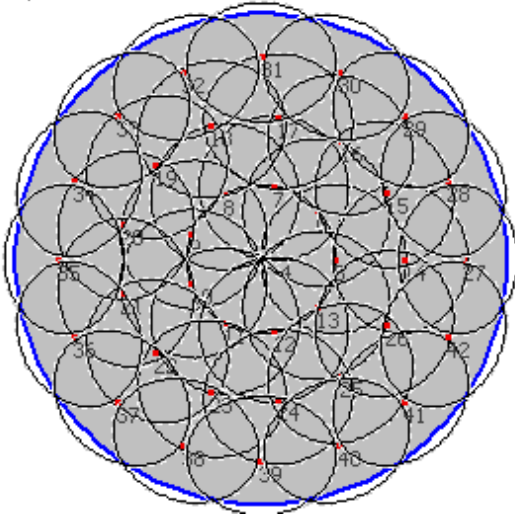


**With
VON**



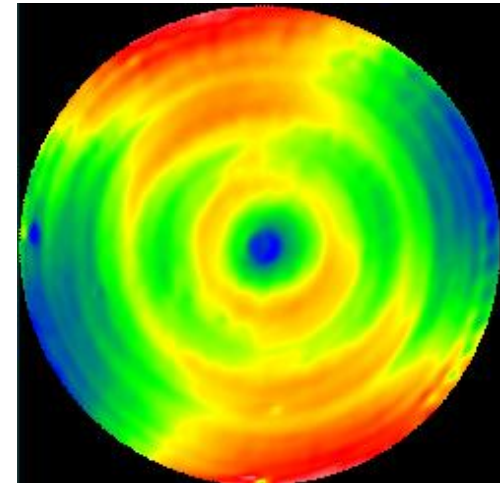
- Only need to match the low-order aberrations of each subaperture, producing resolvable fringes over entire field
- Combine measurement of residuals with nominal wavefront of VON

Measurement Results

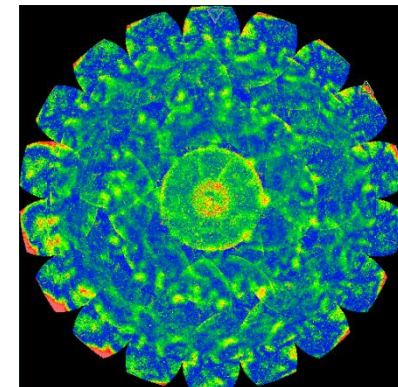


Measurement Lattice

- Measurement result using 6" F/2.2 transmission sphere
- ~40 subapertures
- ~15 minute measurement time
- Low mis-match error (3.6nm)



rms = 147nm



Mis-match map: rms = 3.6nm

PTB Asphere: Measurement Reproducibility and Repeatability

PTB Asphere - Part Id 014542-725-00

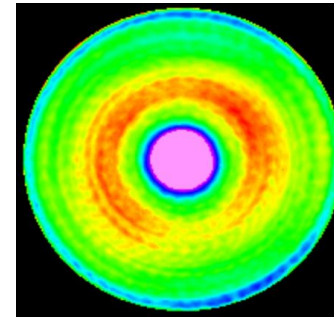
Diameter: 52.2 mm

Departure: 59 μm (93 waves HeNe)

Base radius: 53.312 mm Convex

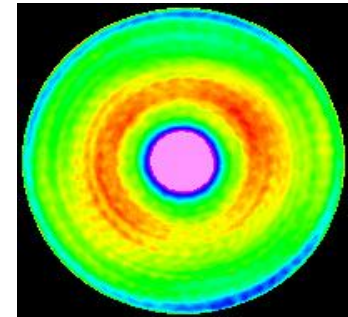
Comparison of measurement results
between 6" F/2.2 and 6" F/3.2

	Mean	Std. Dev.
PV	1.812 μm	0.028 μm
rms	0.278 μm	0.008 μm
R0	53.303 mm	2.3 μm



6" F/2.2

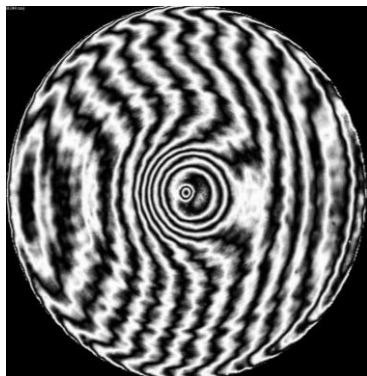
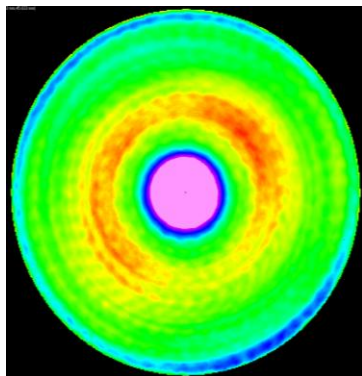
PV = 1.790 μm
rms = 0.278 μm
R0 = 53.308 mm



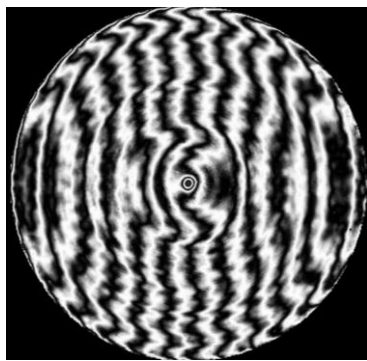
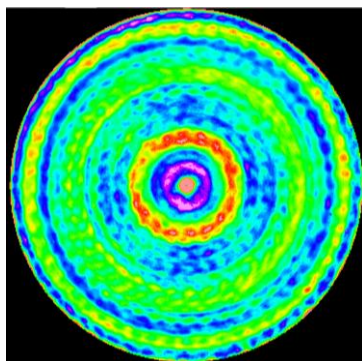
6" F/3.2

PV = 1.789 μm
rms = 0.279 μm
R0 = 53.303 mm

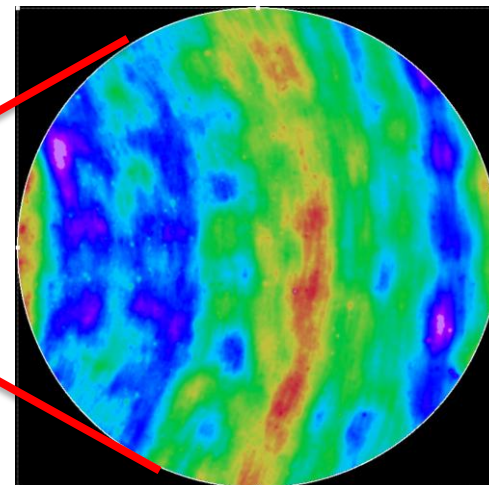
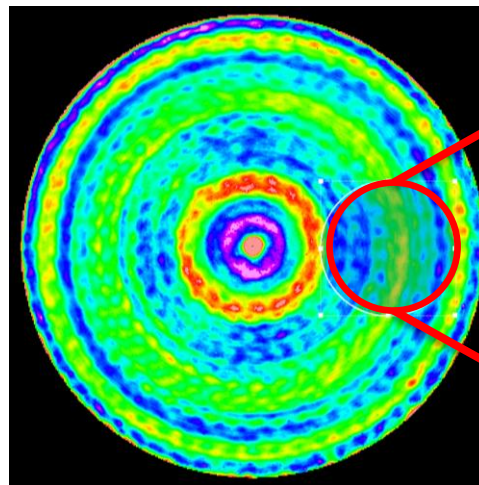
High Resolution Stitching



2000 x 2000 pixel stitch result using 6" F/3.2



2000 x 2000 pixel stitch result using 6" F/3.2
(36 Zernike terms removed to highlight mid-spatial frequencies)



15mm diameter area zoomed to show high resolution

Typical Measurement Times

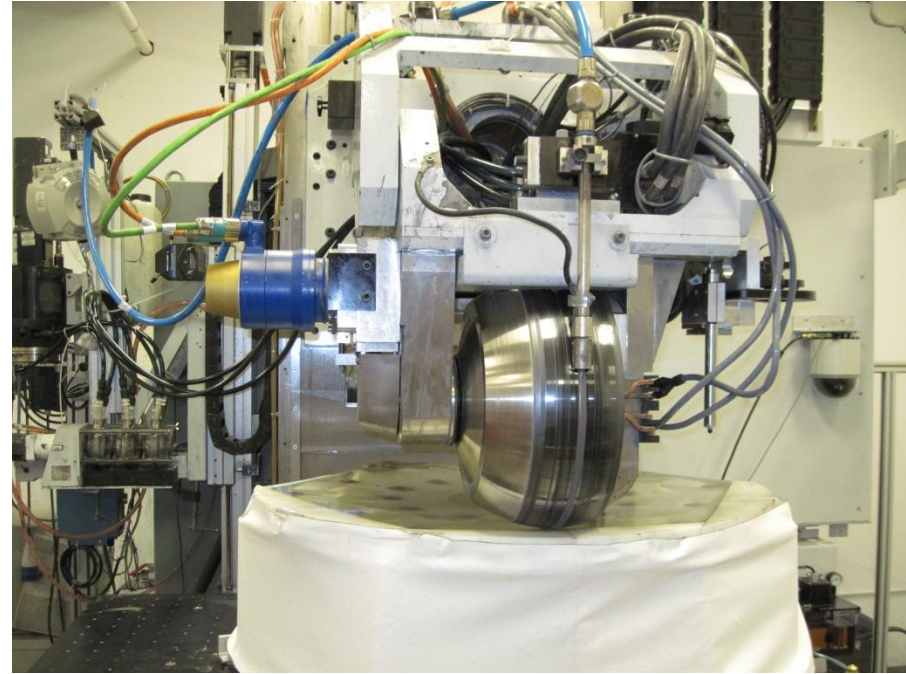
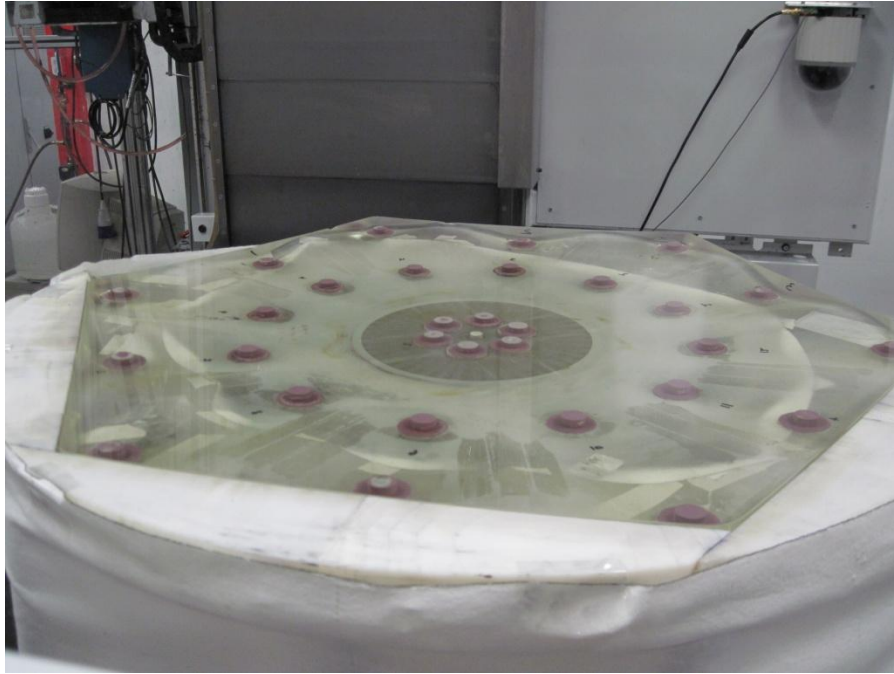
- Set-up times:
 - Standard (known) lens: 1-2 minutes
 - Unknown lens: 4-8 minutes
- Measurement times:
 - Flats/spheres: 5-10 minutes
 - Mild aspheres: 10-20 minutes
 - Steep aspheres: 15-30 minutes
 - Depends largely on optimum transmission sphere availability

Current Limitations / Future work

- On-axis (rotationally symmetric) aspheres only
 - Not a fundamental limitation, only current software
 - Very mild off-axis aspheres can be measured now
- No aspheres with inflection points
 - Future versions of the ASI with different VON designs could possibly measure these
- Can measure aspheres with center holes, as long as the central subaperture “sees” some of the part
- Bigger size ASI...

- The use of configurable null optics with subaperture stitching allows for:
 - Large aspheric departure measurement capability (up to 1000λ)
 - Shorter measurement times (fewer sub-apertures)
- While maintaining all of the original benefits of subaperture stitching interferometry:
 - Full aperture coverage
 - Higher lateral resolution
 - Increased accuracy
 - Aspheric measurements without dedicated nulls

NASA SPOT Mirror MRF Polishing on Q22-950F machine



Shape: Hexagonal concave sphere
Material: Pyrex
Diameter: 870 mm
Wavefront specification: $\lambda/40$ rms
Initial wavefront error: 1.5λ rms

See talk from John Hagopian and
Jason Budinoff at NASA

Effective Characterization of an Asphere's Nominal Shape

Constants and coefficients

$$C = \frac{1}{-71,42}$$

$$K = 0$$

$$A_4 = 0,566322E-06$$

$$A_6 = 0,174788E-9$$

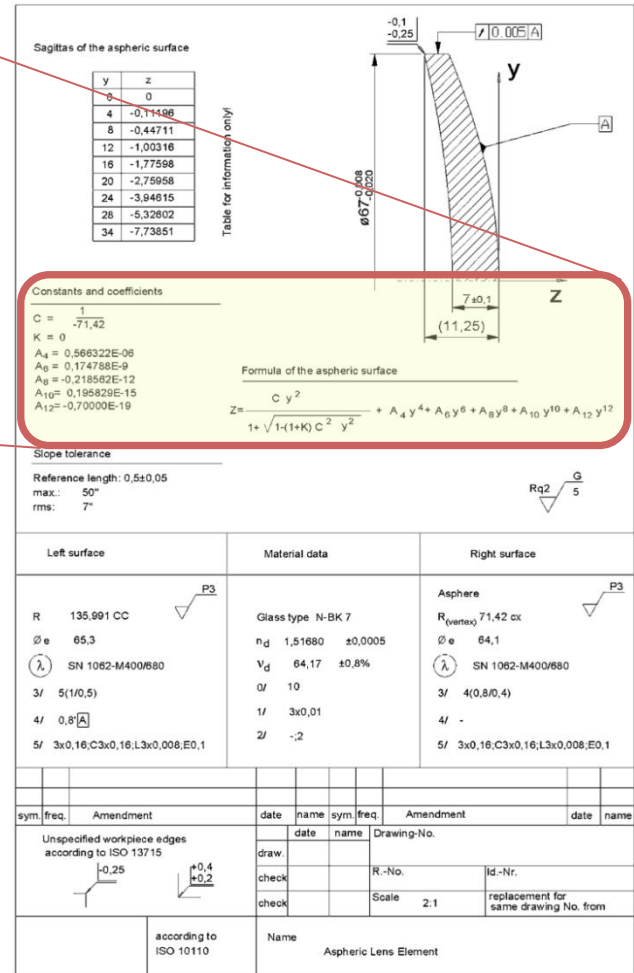
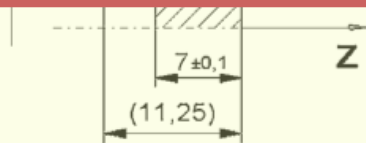
$$A_8 = -0,218562E-12$$

$$A_{10} = 0,195829E-15$$

$$A_{12} = -0,70000E-19$$

Formula of the aspheric surface

$$Z = \frac{C y^2}{1 + \sqrt{1 - (1+K) C^2 y^2}} + A_4 y^4 + A_6 y^6 + A_8 y^8 + A_{10} y^{10} + A_{12} y^{12}$$



Many issues with current representation:

Significant digits ?

- Accuracy ?
- Difficult to constraint etc.

a more effective alternative (“Forbes Representation”) has been developed with orthogonal polynomials. See

www.qedmrf.com after 6/15/10 for details...



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